US 20240117803A1

(19) United States
(12) Patent Application Publication
Sames et al.
(10) Pub. No.: US 2024/0117803 A1
(43) Pub. Date: Apr. 11, 2024

(54) **RECIPROCATING PUMP WITH RESERVOIR FOR COLLECTING AND CONTROLLING WORKING FLUID LEVEL WITHOUT THE USE OF PISTON SEALS**

(71) Applicant: **Cinco Research Corporation**, Elizabethton, TN (US)

(72) Inventors: **William Sames**, Johnson City, TN (US); **Amos Manneschmidt**, Knoxville, TN (US)

(21) Appl. No.: **18/322,791**

(22) Filed: **May 24, 2023**

Related U.S. Application Data

(60) Provisional application No. 63/378,535, filed on Oct. 6, 2022.

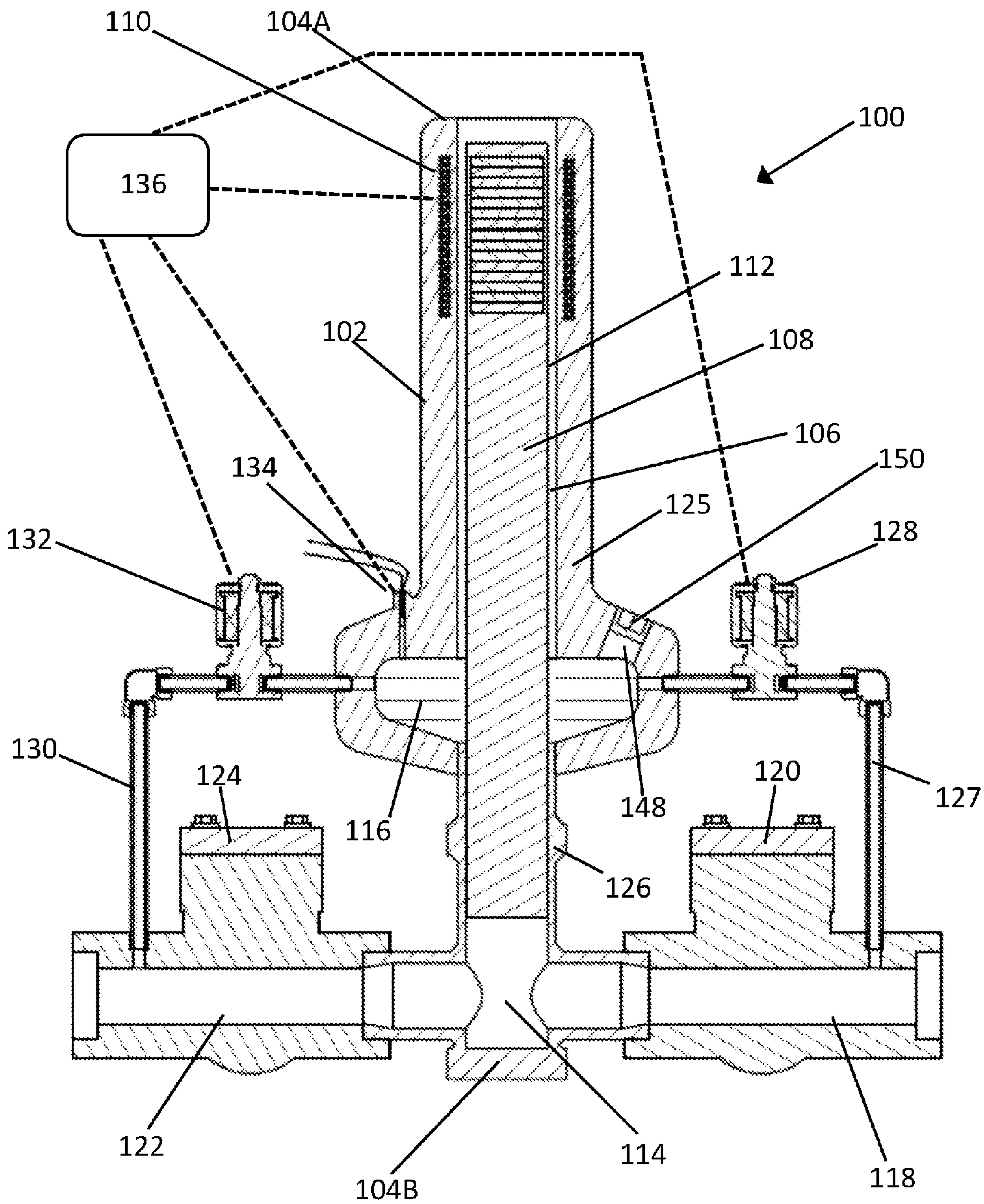
Publication Classification

(51) **Int. Cl.**
F04B 49/03 (2006.01)
F04B 19/22 (2006.01)
F04B 23/02 (2006.01)

(52) **U.S. Cl.**
CPC ***F04B 49/03*** (2013.01); ***F04B 19/22*** (2013.01); ***F04B 23/02*** (2013.01)

(57) **ABSTRACT**

A reciprocating pump with a reservoir for collecting and controlling a working fluid level without the use of piston seals. A method of collecting and controlling a working fluid level in a reciprocating pump which has no piston seals.



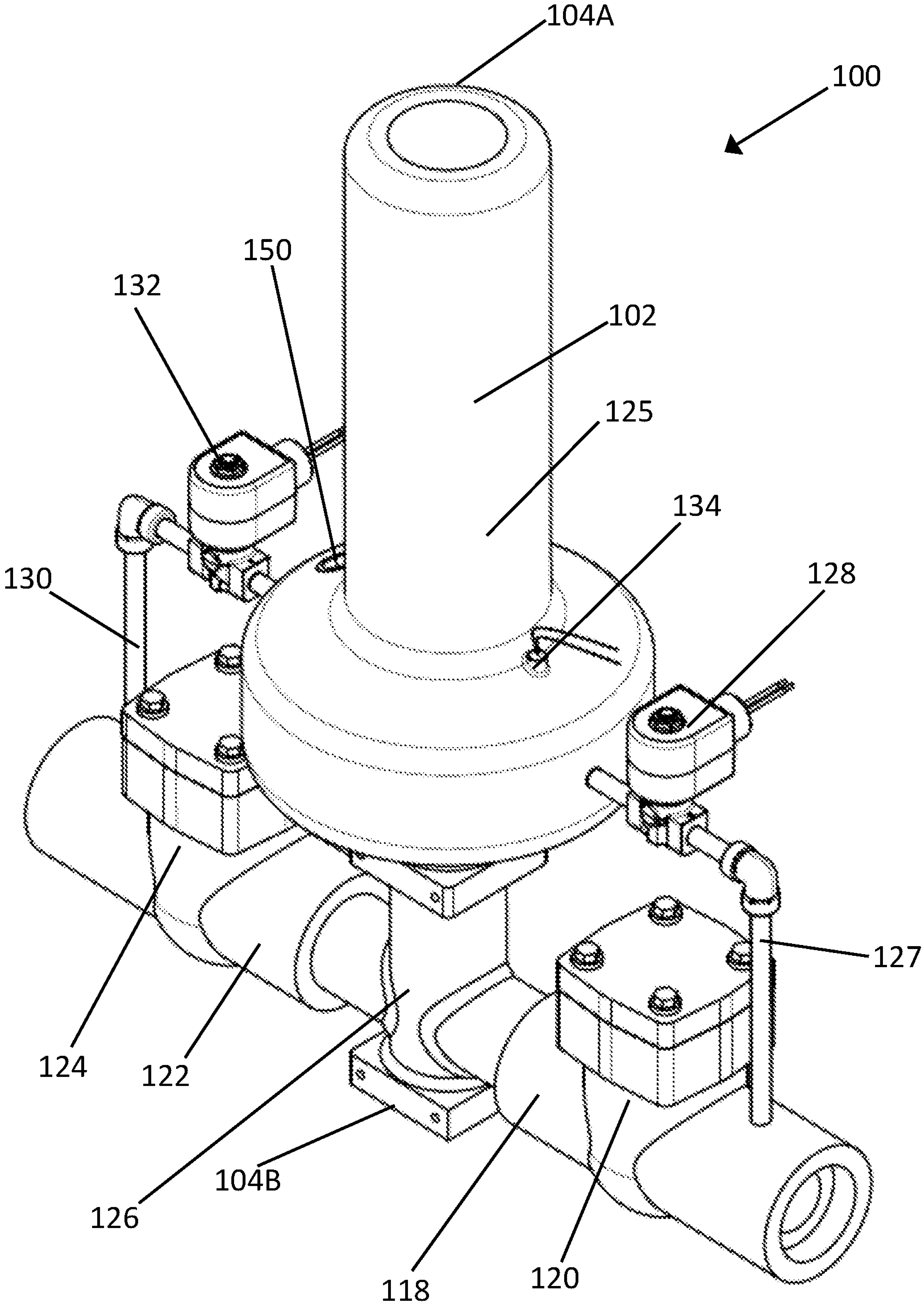

104A
100
150
132
102
125
134
130
128
127
124
122
126
104B
118
120

FIG. 1

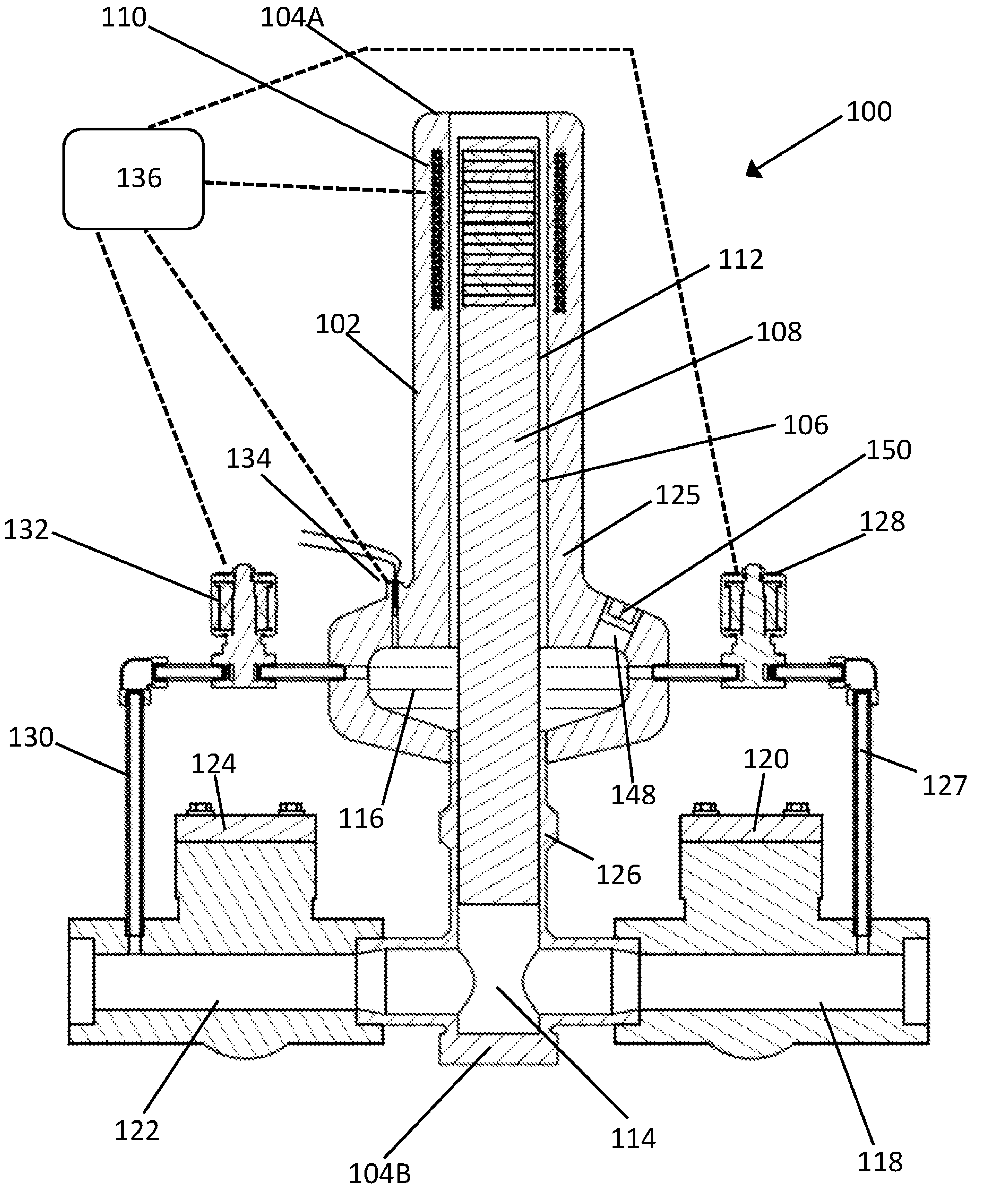

110
104A
100
136
112
102
108
106
134
150
125
132
128
130
124
120
127
116
148
126
122
104B
114
118

FIG. 2

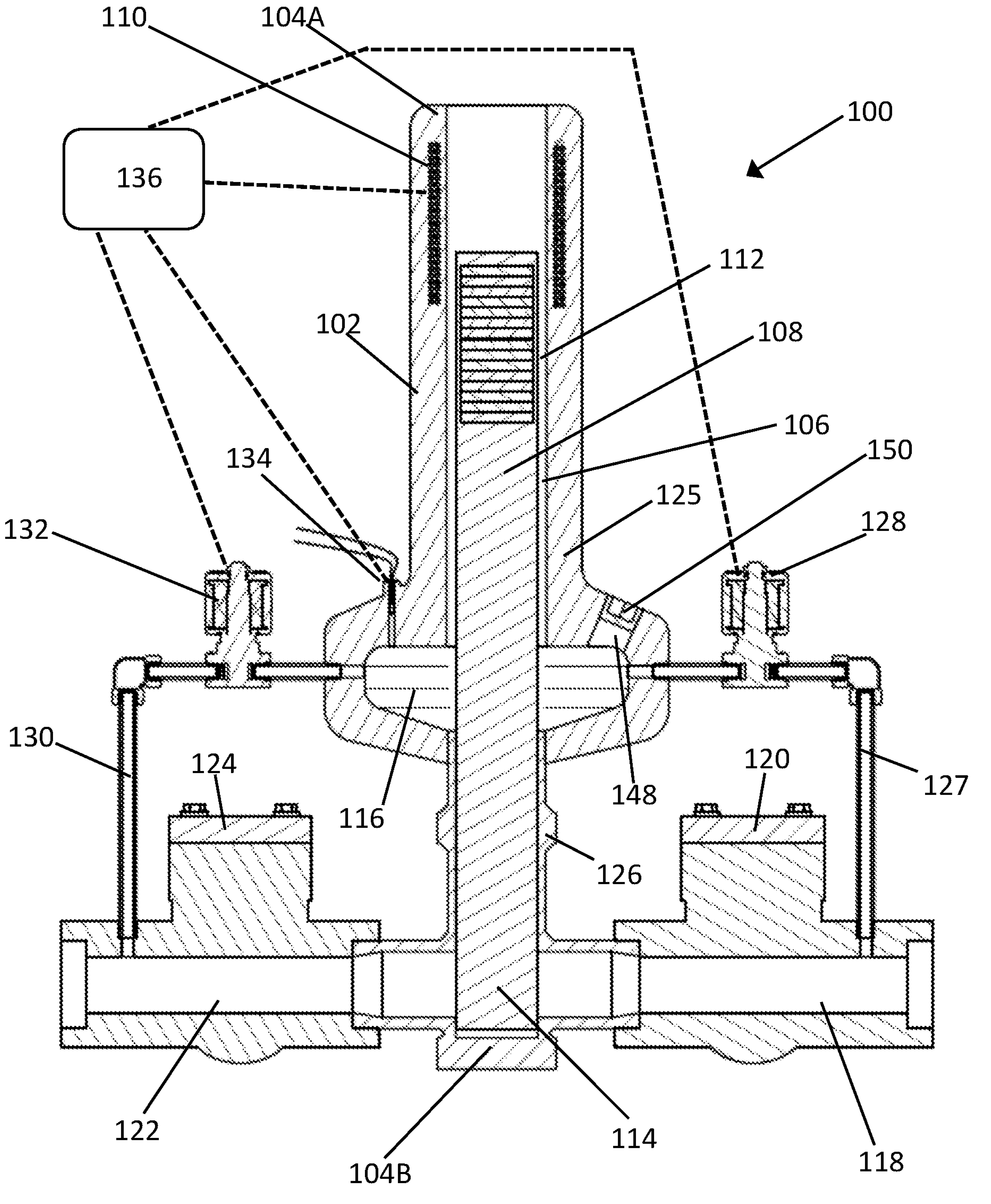
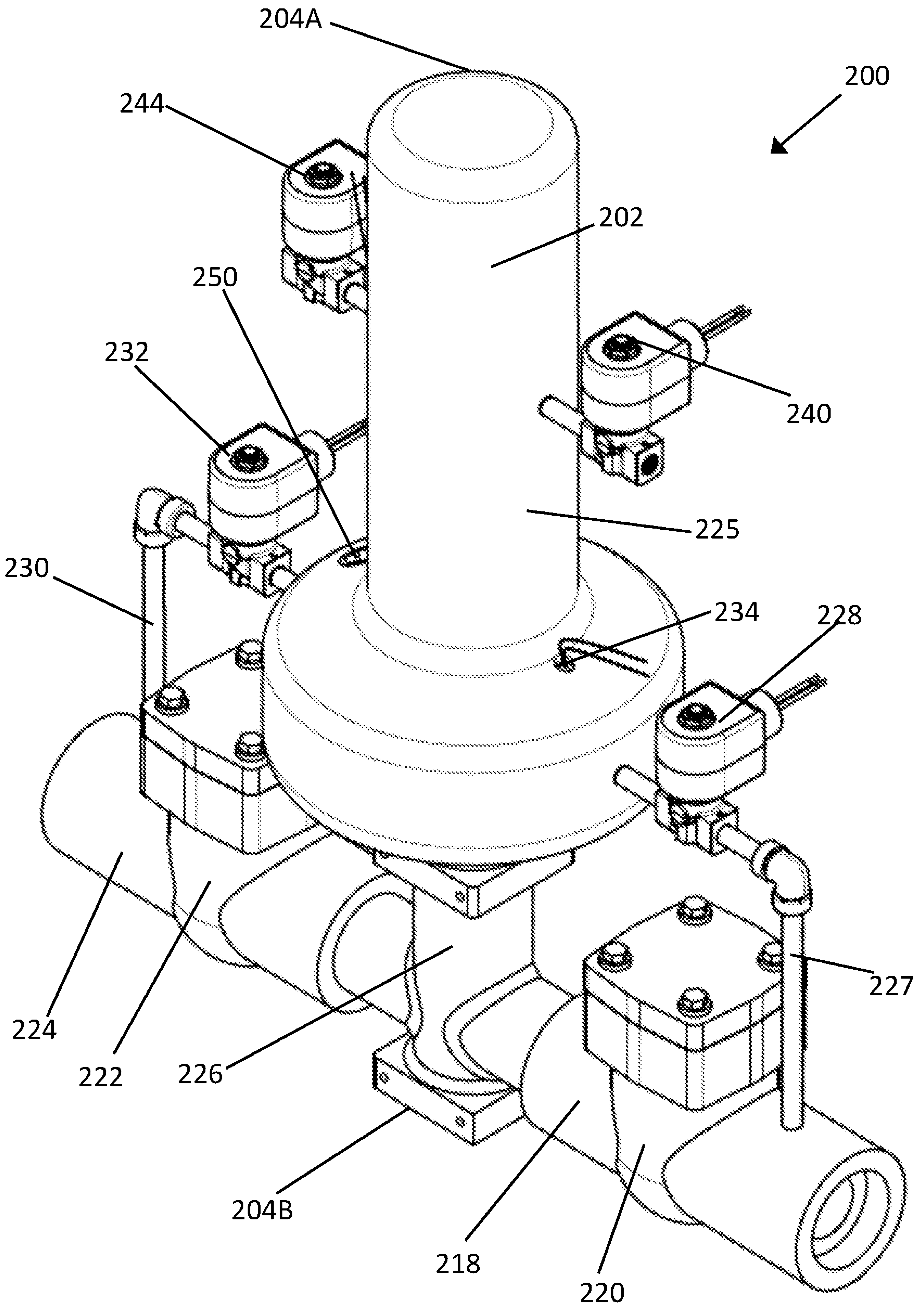

110
104A
100
136
112
102
108
106
134
150
125
132
128
130
124
120
127
116
148
126
122
104B
114
118

FIG. 3



204A
200
244
202
250
232
240
225
230
234
228
227
224
222
226
204B
218
220

FIG. 4

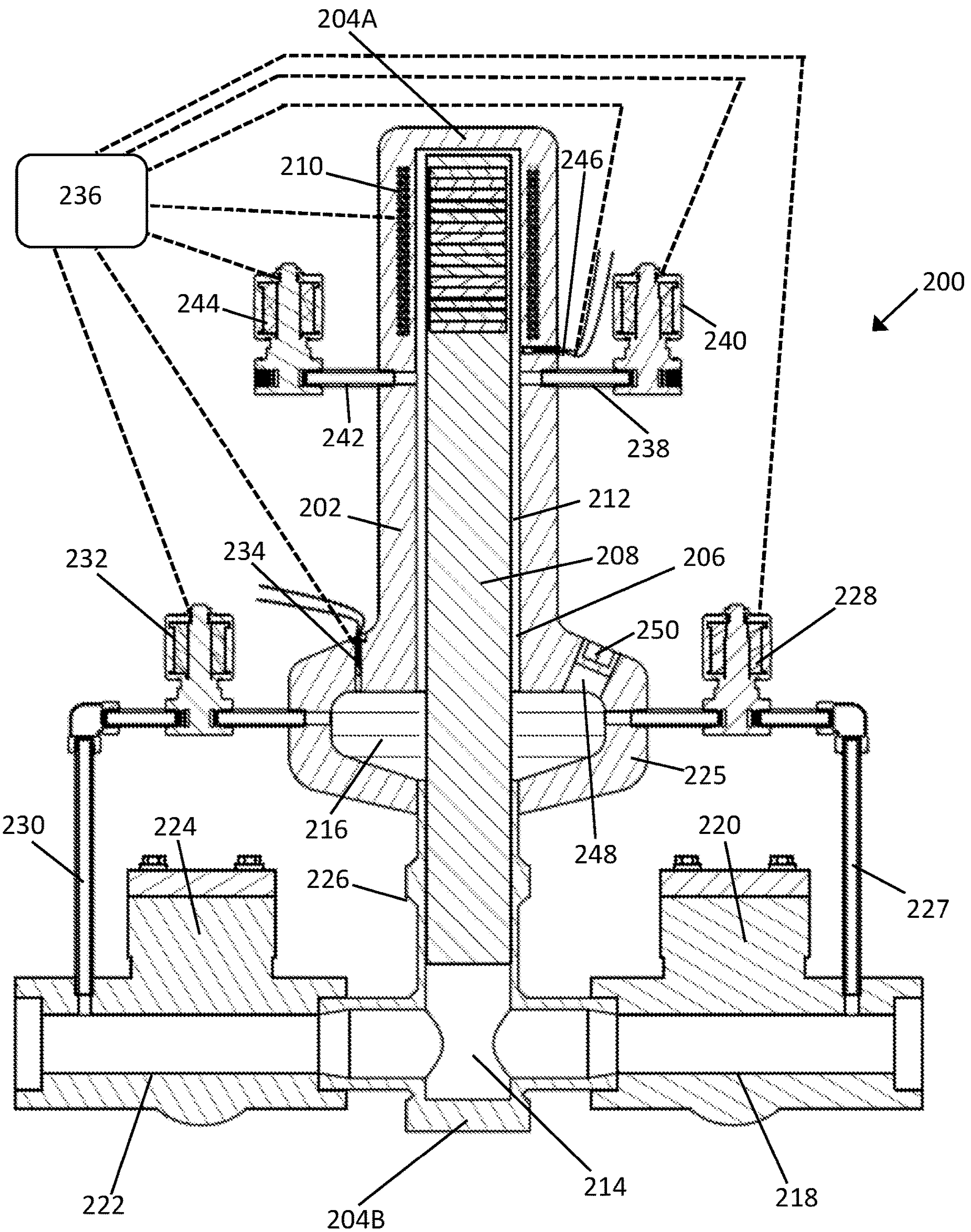

204A
236
210
246
244
240
200
242
238
202
212
232
234
208
206
228
250
225
216
248
230
224
220
226
227
222
204B
214
218

FIG. 5

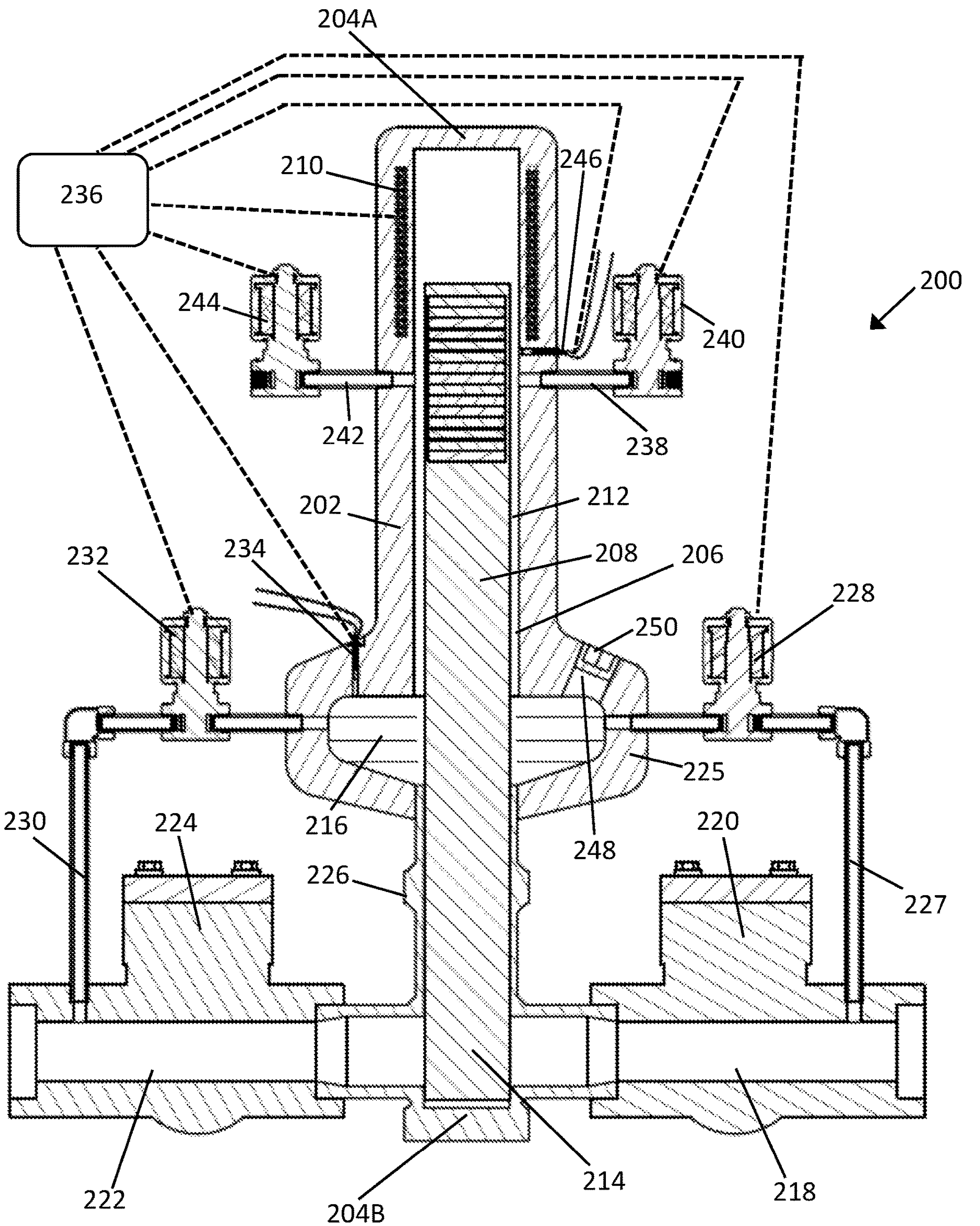

204A
236
210
246
244
240
200
242
238
202
212
208
206
232
234
228
250
216
225
248
230
224
220
226
227
222
204B
214
218

FIG. 6

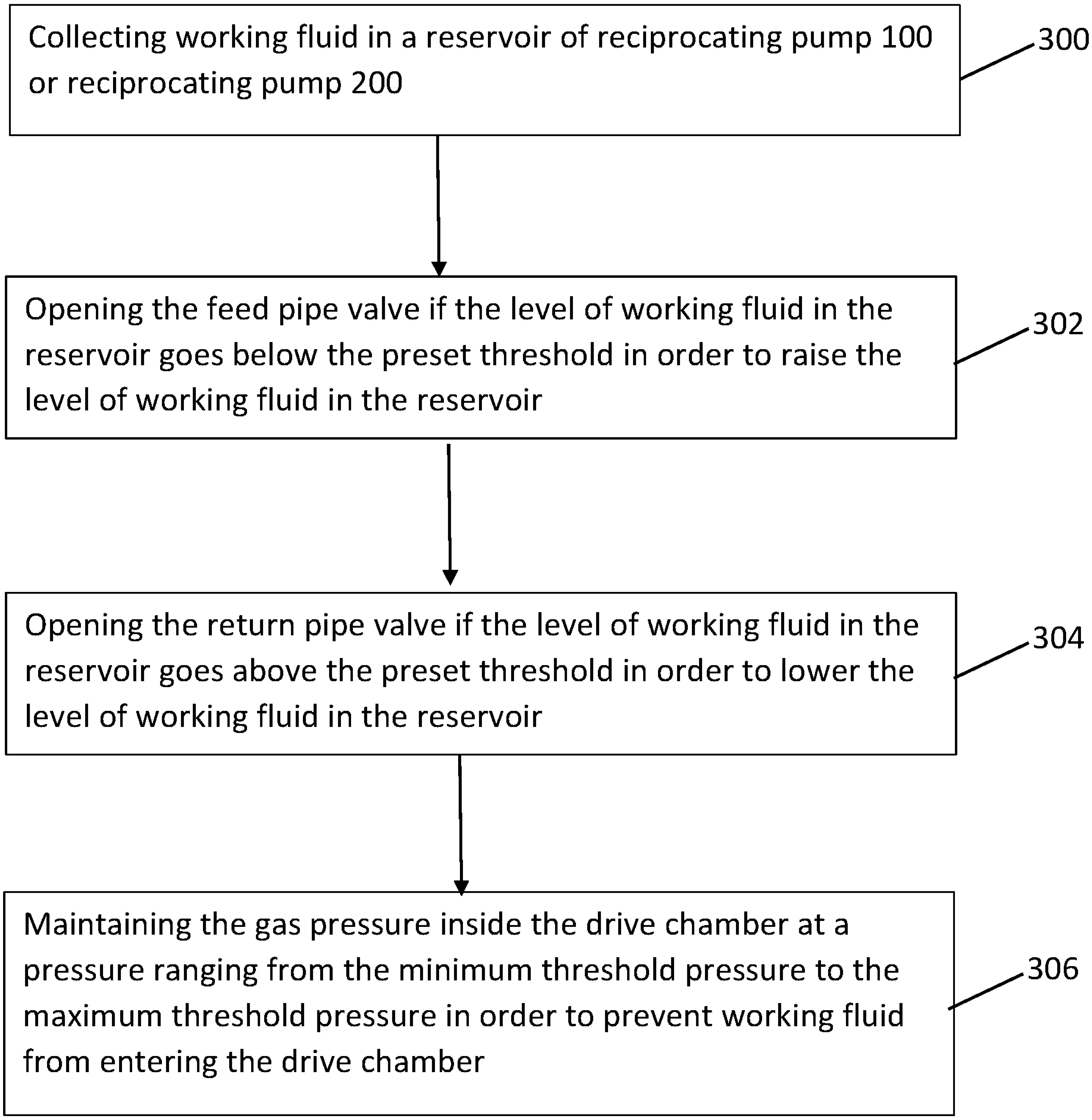

Collecting working fluid in a reservoir of reciprocating pump 100 or reciprocating pump 200
300
Opening the feed pipe valve if the level of working fluid in the reservoir goes below the preset threshold in order to raise the level of working fluid in the reservoir
302
Opening the return pipe valve if the level of working fluid in the reservoir goes above the preset threshold in order to lower the level of working fluid in the reservoir
304
Maintaining the gas pressure inside the drive chamber at a pressure ranging from the minimum threshold pressure to the maximum threshold pressure in order to prevent working fluid from entering the drive chamber
306

FIG. 7

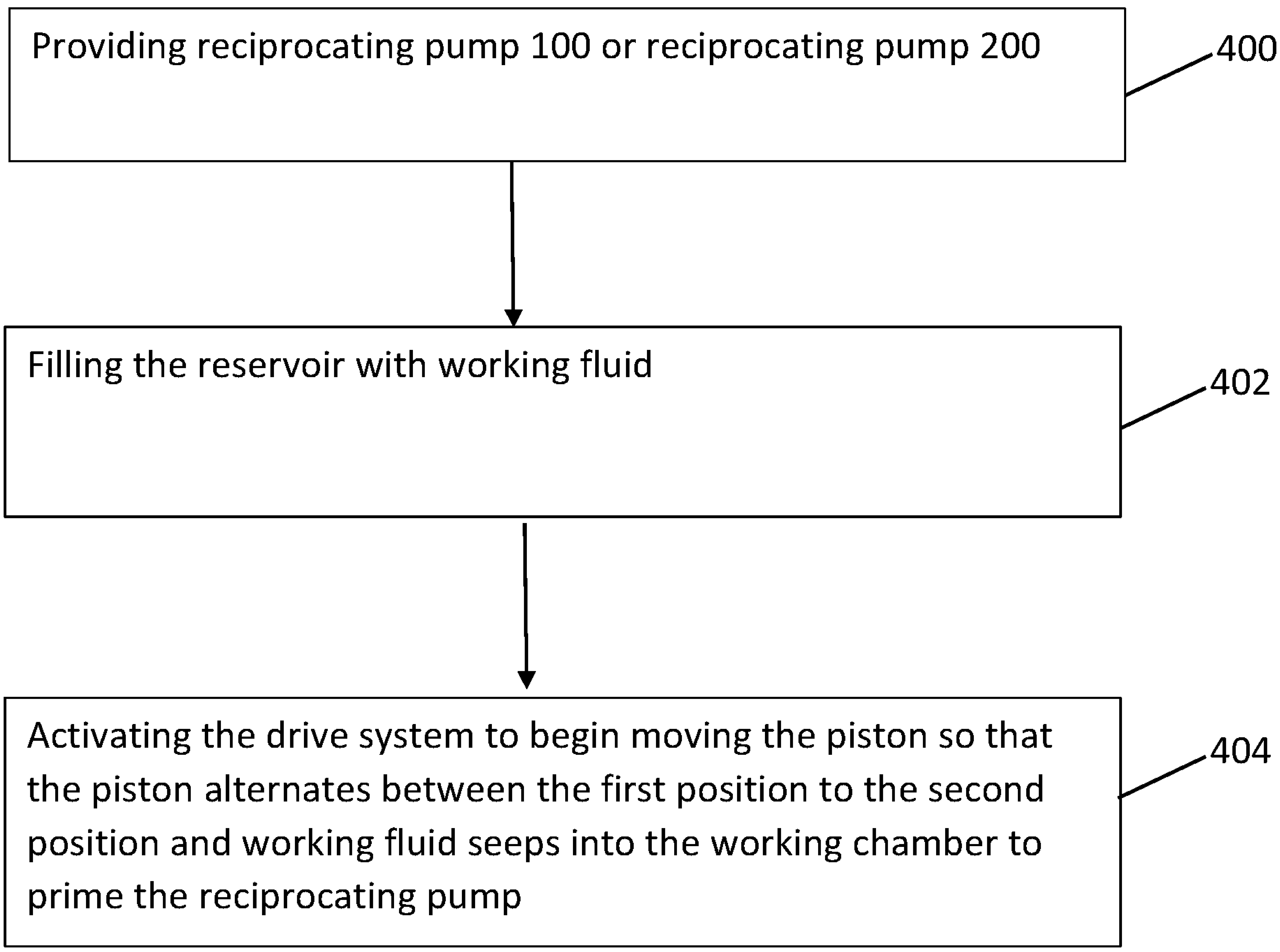

Providing reciprocating pump 100 or reciprocating pump 200
400
Filling the reservoir with working fluid
402
Activating the drive system to begin moving the piston so that the piston alternates between the first position to the second position and working fluid seeps into the working chamber to prime the reciprocating pump
404

FIG. 8

RECIPROCATING PUMP WITH RESERVOIR FOR COLLECTING AND CONTROLLING WORKING FLUID LEVEL WITHOUT THE USE OF PISTON SEALS

STATEMENT AS TO INVENTION RIGHTS UNDER FEDERALLY SPONSORED RESEARCH

[0001] This invention was made with government support under Grant No. DE-SC0021764 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

FIELD

[0002] This disclosure relates to the field of pumps. More particularly, this disclosure relates to reciprocating pumps for transferring fluids.

BACKGROUND

[0003] Pumps that utilize a piston to create positive displacement of a working fluid are a very old method of pumping liquids that has been in use since at least 250 BCE. Historically, such pumps have utilized seals to prevent the backflow or leakage of working fluid past the piston. Such pumps have typically been used for processing viscous fluids in applications such as paint, adhesive, and glaze production. The seals used in such pumps have typically been made of rubber, plastic, and other compliant materials and are replaceable in nature. Such pumps typically have operational temperature ranges that are therefore limited by the operational temperature(s) of such seals. Some applications require higher operating temperatures such as for example, the pumping of molten salt. Traditional piston pump seals, therefore, provide a significant operational limitation. Additionally, for lower temperature applications, the use of such seals and lubricating substances can introduce contaminants into a working fluid. The seals can degrade over time and/or the lubricant used can leach into the working fluid. This can be particularly problematic if the pump being used is for a hygienic application that requires a very high purity working fluid. Such applications may include, for example, food processing.

[0004] Ceramic pistons, compared to metal or metal alloy pistons, have a known wear resistance advantage and have a higher temperature operational ceiling in such types of pumps and are produced commercially, typically with a ceramic built around a metal shaft that can be connected to a driving mechanism. An example of such a pump is disclosed in U.S. Pat. No. 7,134,851 entitled "Reciprocating Pump Having a Ceramic Piston" to Chenoweth, the entire contents of which are incorporated herein by reference. The terms "reciprocating pump" and "piston pump" are used herein interchangeably to refer to positive displacement pumps that utilize a piston. Examples include pumps described in U.S. Patent Application Publication Number 2010/0326271 entitled "Reciprocating Pump And Method For Making A System With Enhanced Dynamic Seal Reliability" to Stang, U.S. Patent Application Publication Number 2006/0127252 entitled "Reciprocating Pump System" to Caddell, and U.S. Patent Application Publication Number 2006/0045782 entitled "Low-Friction Reciprocating Pump" to Kretzinger, and U.S. Pat. No. 5,403,169 entitled "Plunger Pump" to Yokoi, the entire contents of which are incorporated herein by reference. Although the ceramic components allow for high temperature operation, such pumps are still limited by the seals required to prevent leakage around a piston during operation. Some have tried moving seals far back from a front of a piston (e.g., U.S. Patent Application Publication Number 2006/0045782 entitled "Low-Friction Reciprocating Pump" to Kretzinger et al., the entire contents of which are incorporated herein by reference), but such pumps nonetheless still require seals with the inherent limitations described above. Check valves are less of a problem, because graphite seals can be used to seal the interior valve area and the seal is self-reinforcing with increasing dynamic pressure unlike with the seal between a piston and cylinder body. However, seals traditionally used around a piston in a piston pump have definite temperature limitations.

[0005] What is needed, therefore, is a pump design capable of operating at a wide range of temperatures including high temperatures (e.g., above 400° C.) without the limitations described above with conventional piston pump seals.

SUMMARY

[0006] The above and other needs are met by a reciprocating pump including a piston, a pump cavity, and a reservoir for collecting working fluid along the pump cavity wherein the pump does not utilize any seals along the piston of pump cavity, thereby allowing working fluid to escape a working chamber into the reservoir. This is useful in high temperature applications like the pumping of molten salt where seals would be destroyed by the high temperatures, and this application is also useful in lower temperature, hygienic applications in which the seals could degrade over time and the lubricant could leach into the working fluid, both causing contamination of the working fluid.

[0007] In a preferred embodiment, a reciprocating pump is disclosed, the pump comprising a pump shell including a pump shell first end and a pump shell second end; a pump cavity inside the pump shell, the pump cavity further comprising: a working chamber proximate to the pump shell second end; a drive chamber proximate to the pump shell first end; and a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid. The reciprocating pump further comprises a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity; a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe; a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity; a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe; a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe; a drive system engaged with the piston for driving the piston inside the pump cavity; a return pipe in fluid communication with the reservoir and the suction pipe; a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe; a feed pipe in fluid communication with the reservoir and the delivery pipe; a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe; a reservoir sensor for sensing a level of working fluid in the reservoir; and a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to: open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold. Preferably, the control system is also preferably operable to close the feed pipe valve if the level of working fluid goes above a preset threshold. Similarly, the control system is preferably operable to close the return pipe if the level of working fluid in the reservoir goes below a preset threshold.

[0008] In a preferred embodiment, the reciprocating pump does not include any seals in the pump cavity or along the piston such that some working fluid is permitted to escape the working chamber and move into the reservoir during operation of the reciprocating pump.

[0009] In one embodiment, the pump shell includes a first end and a second end and wherein the first end is open to ambient atmosphere.

[0010] In another embodiment, the pump shell includes a first end and a second end and wherein the first end is closed to the atmosphere.

[0011] In a preferred embodiment, the drive system comprises an electromagnetic driving unit and wherein the control system is operable to control the electromagnetic driving unit to cause the piston to move and alternate between the first position and the second position.

[0012] In a preferred embodiment in which the first end of the pump shell is closed to ambient atmosphere, the reciprocating pump further comprises a gas feed line in fluid communication with the drive chamber; a gas feed line valve located along the gas feed line for controlling flow of gas into the drive chamber; a gas release line in fluid communication with the drive chamber; a gas release line valve located along the gas release line for controlling flow of gas out of the drive chamber; a pressure sensor for sensing the pressure of gas inside the drive chamber; and the control system in communication with the gas feed line valve, the gas release line valve, and the pressure sensor wherein the control system is operable to: open the gas feed line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to fall below a minimum threshold pressure; and open the gas release line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to reach a maximum threshold pressure. The control system is preferably further operable to: close the gas feed line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to go above a minimum threshold pressure; and close the gas release line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to fall below a maximum threshold pressure. The operations of the control system are preferably operable to control the pressure of gas in the drive chamber to limit the amount of working fluid that escapes from the working chamber to the reservoir and to prevent the working fluid from entering the drive chamber.

[0013] In the various embodiments described above, the pump shell, the pump piston, the suction valve, and the delivery valve may be made of material comprising metal or metal alloy. Additionally or alternatively, in the various embodiments described above, the pump shell, the pump piston, the suction valve, and the delivery valve may be made of material comprising ceramic. Additionally or alternatively, in the various embodiments described above, the pump shell, the pump piston, the suction valve, and the delivery valve may be made of material comprising plastic.

[0014] In the various embodiments described above, the suction valve may comprise a first check valve and the delivery valve may comprise a second check valve.

[0015] In the various embodiments described above, the return pipe valve may comprise a first solenoid valve and the feed pipe valve may comprise a second solenoid valve.

[0016] In another aspect, a method of controlling the flow of working fluid being pumped through a reciprocating pump which uses no seals along a pump piston or pump cavity is disclosed. The method preferably comprises collecting working fluid in a reservoir of a reciprocating pump, the reciprocating pump comprising: a pump shell including a pump shell first end and a pump shell second end; a pump cavity inside the pump shell, the pump cavity further comprising: a working chamber proximate to the pump shell second end; a drive chamber proximate to the pump shell first end; and a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid; a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity; a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe; a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity; a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe; a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe; a drive system engaged with the piston for driving the piston inside the pump cavity; a return pipe in fluid communication with the reservoir and the suction pipe; a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe; a feed pipe in fluid communication with the reservoir and the delivery pipe; a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe; a reservoir sensor for sensing a level of working fluid in the reservoir; and a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to: open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold. The method preferably further includes opening the feed pipe valve if the level of working fluid in the reservoir goes below the preset threshold in order to raise the level of working fluid in the reservoir. The method preferably further comprises opening the return pipe valve if the level of working fluid in the reservoir goes above the preset threshold in order to lower the level of working fluid in the reservoir.

[0017] In one embodiment of the method described above, the reciprocating pump further comprises: a gas feed line in fluid communication with the drive chamber; a gas feed line valve located along the gas feed line for controlling flow of gas into the drive chamber; a gas release line in fluid communication with the drive chamber; a gas release line valve located along the gas release line for controlling flow of gas out of the drive chamber; a pressure sensor for sensing the pressure of gas inside the drive chamber; and the control system in communication with the gas feed line valve, the gas release line valve, and the pressure sensor wherein the control system is operable to: open the gas feed line valve if the gas pressure inside the drive chamber is sensed by the pressure sensor to fall to a minimum threshold pressure; and open the gas release line valve if the gas pressure inside the drive chamber is sensed by the pressure sensor to reach to a maximum threshold pressure. In this embodiment, the method preferably further comprises maintaining the gas pressure inside the drive chamber at a pressure ranging from the minimum threshold pressure to the maximum threshold pressure in order to prevent working fluid from entering the drive chamber.

[0018] In the various methods described above, the working fluid may comprise a liquid. In the various methods described above, the working fluid may consist of a liquid. In the various methods described above, the working fluid may comprise a multi-phase mixture of liquid, gas, and solids. In the various methods described above, the working fluid may comprise molten salt. In the various methods described above, the working fluid may consist of molten salt.

[0019] In the various methods described above, the working fluid may have a temperature of greater than 100° C. In the various methods described above, the working fluid may have a temperature of greater than 400° C.

[0020] In another aspect, a method of priming a reciprocating pump which uses no seals along a pump piston or pump cavity is disclosed. The method preferably comprises providing a pump comprising: a pump shell including a pump shell first end and a pump shell second end; a pump cavity inside the pump shell, the pump cavity further comprising: a working chamber proximate to the pump shell second end; a drive chamber proximate to the pump shell first end; and a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid; a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity; a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe; a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity; a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe; a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe; a drive system engaged with the piston for driving the piston inside the pump cavity; a return pipe in fluid communication with the reservoir and the suction pipe; a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe; a feed pipe in fluid communication with the reservoir and the delivery pipe; a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe; a reservoir sensor for sensing a level of working fluid in the reservoir; and a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to: open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold. The method preferably further comprises filling the reservoir with working fluid. The method preferably further comprises activating the drive system to begin moving the piston so that the piston alternates between the first position to the second position and working fluid seeps into the working chamber to prime the reciprocating pump.

[0021] The summary provided herein is intended to provide examples of particular disclosed embodiments and is not intended to cover all potential embodiments or combinations of embodiments. Therefore, this summary is not intended to limit the scope of the invention disclosure in any way, a function which is reserved for the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Further features, aspects, and advantages of the present disclosure will become better understood by reference to the following detailed description, appended claims, and accompanying figures, wherein elements are not to scale so as to more clearly show the details, wherein like reference numbers indicate like elements throughout the several views, and wherein:

[0023] FIG. **1** shows a perspective view of a first embodiment of a reciprocating pump;

[0024] FIG. **2** shows a cross-sectional cutaway view of the reciprocating pump shown in FIG. **1** with a piston positioned in a first position;

[0025] FIG. **3** shows the reciprocating pump shown in FIG. **2** with the piston positioned in a second position;

[0026] FIG. **4** shows a perspective view of a second embodiment of a reciprocating pump;

[0027] FIG. **5** shows a cross-sectional cutaway view of the reciprocating pump shown in FIG. **4** with a piston positioned in a first position;

[0028] FIG. **6** shows the reciprocating pump shown in FIG. **5** with the piston positioned in a second position;

[0029] FIG. **7** shows operations of a method of controlling the flow of working fluid being pumped through a reciprocating pump which uses no seals along a pump piston or pump cavity; and

[0030] FIG. **8** shows operations of a method of priming a reciprocating pump which uses no seals along a pump piston or pump cavity.

[0031] The figures are provided to illustrate concepts of the invention disclosure and are not intended to embody all potential embodiments of the invention. Therefore, the figures are not intended to limit the scope of the invention disclosure in any way, a function which is reserved for the appended claims.

DETAILED DESCRIPTION

[0032] Generally disclosed herein is a reciprocating pump and method of using such reciprocating pump. Typically, seals made of rubber or polymeric materials are used on or adjacent to pistons in reciprocating pumps. Seals are an important feature to prevent working fluid in a pump cavity from seeping past a piston into a drive chamber of such pump. However, some applications require the pumping of very hot fluids such as, for example, molten salt. Temperatures of molten salt can easily reach over 400° C. In such applications, seals made of rubber and polymeric materials would fail due to the high temperatures involved. Using a reciprocating pump without seals along or adjacent to pump pistons would result in leakage of working fluid into a drive chamber. Therefore, using a reciprocating pump without such seals is counterintuitive because such seals are seen as a necessary part of reciprocating pumps for their proper function. This disclosure describes a counterintuitive solution to the problems discussed above.

[0033] FIGS. **1-3** show a first embodiment of a reciprocating pump **100** including a pump shell **102** having a pump shell first end **104**A and a pump shell second end **104**B, a pump cavity **106**, a piston **108**, and a drive system **110** for driving the piston **108** to alternate between a first position shown in FIG. **2** and a second position shown in FIG. **3**. The drive system **110** is either mechanically and/or electromagnetically engaged with the piston **108** to drive the piston **108**. Importantly, the reciprocating pump **100** does not include any seals along the piston **108** or the pump cavity **106**. The pump shell first end **104**A of the reciprocating pump **100** is open to ambient atmosphere as shown in FIG. **1**. The pump cavity **104** further includes a drive chamber **112** located proximate to the pump shell first end **104**A, a working chamber **114** located proximate to the pump shell second end **104**B, and a reservoir **116** which is effectively a bulge in the pump cavity **106** between drive chamber **112** and the working chamber **114**. The reservoir **116** is preferably shaped as an annular ring. The drive chamber **112** and the working chamber **114** are preferably cylindrical in shape. Similarly, the piston **108** is preferably cylindrical in shape. The movement of the piston **108** causes working fluid to be drawn through a suction pipe **118** including a suction valve **120** into the working chamber **114** (with the delivery valve **124** closed) and then expel said working fluid out of the working chamber **114** through a delivery pipe **122** including a delivery valve **124** (with the suction valve **120** closed). The suction valve **120** and the delivery valve **124** are preferably mechanical check valves. Although check values are specified here, other types of valves may be used. In some embodiments, the reciprocating pump **100** pump shell **102** is formed of two parts including a first shell member **125** and a second shell member **126**. The second shell member **126** often is a “T” shaped member, to which the suction pipe **118** and the delivery pipe **122** are attached, preferably by welding. In such embodiments, the working chamber **114** is typically located inside the second shell member **126**. The first shell member **125** and the second shell member **126** are attached together, preferably by welding.

[0034] The drive system **110** preferably includes an electromagnetic driving unit such as the one described in U.S. Patent Application Publication Number 2017/0268491 entitled “Fluid Pump” to Ho, or the one described in U.S. Pat. No. 3,740,171 entitled “Electromagnetic Pump or Motor Device” to Farkos, the entire contents and teachings of which are incorporated herein by reference in their entireties. Although an electromagnetic drive system is shown in the figures, other drive systems are contemplated and could be used or adapted to work as a part of the reciprocating pump **100**. For example, mechanical drive systems such as that described in U.S. Pat. No. 5,403,169 entitled “Plunger Pump” to Yokoi et al., can be used. The entire contents and teachings of this reference is incorporated herein by reference. A mechanical crank with one or more connecting rods may also be used as the drive system **110**.

[0035] The reciprocating pump **100** preferably further includes a return pipe **127** in fluid communication with the reservoir **116** and the suction pipe **118**. A return pipe valve **128** located along the return pipe **127** is used for controlling flow of working fluid through the return pipe **127**. The reciprocating pump **100** further includes a feed pipe **130** in fluid communication with the reservoir **116** and the delivery pipe **122**. A feed pipe valve **132** located along the feed pipe **130** is used for controlling flow of working fluid through the feed pipe **130**.

[0036] The reciprocating pump **100** preferably further includes a reservoir sensor **134** for sensing a level of working fluid in the reservoir **116**. The reciprocating pump **100** preferably further includes a control system **136** in communication with the reservoir sensor **134**, the return pipe valve **128**, and the feed pipe valve **132**. The control system **136** may include a classic programmable logic controller (PLC), a computer or computers including one or more processors, a custom electronic printed circuit board (PCB), or other control device known to persons having ordinary skill in the art. The control system **136** may be in communication with an electromagnetic drive as shown in the figures. The control system **136** may be connected to these components using wires, through a wireless connection, or combinations thereof. The control system **136** is preferably operable to open the feed pipe valve **132** if the level of working fluid in the reservoir **116** reaches or goes below a preset threshold; and/or open the return pipe valve **128** if the level of working fluid in the reservoir **116** reaches or goes above a preset threshold. The control system **136** is also preferably operable to close the feed pipe valve **132** if the level of working fluid goes above a preset threshold. Similarly, the control system **136** is operable to close the return pipe valve **128** if the level of working fluid in the reservoir **116** goes below a preset threshold. In a preferred embodiment, the control system **136** can be configured to make sure that the feed pipe valve **132** and the return pipe valve **128** are not open at the same time. The level of working fluid is indicated by the reservoir sensor **134** with data fed to the control system **136**. Pressure created by action of the piston **108** helps to force working fluid through the feed pipe **130** into the reservoir **116** when the feed pipe valve **132** is open. The return pipe valve **128** and the feed pipe valve **132** are preferably solenoid valves, but other types of computer-controlled valves known to persons having ordinary skill in the art may be used.

[0037] FIGS. **4-6** show a second embodiment of a reciprocating pump **200** including a pump shell **202** having a pump shell first end **204**A and a pump shell second end **204**B, a pump cavity **206**, a piston **208**, and a drive system **210** for driving the piston **208** to alternate between a first position shown in FIG. **5** and a second position shown in FIG. **6**. The drive system **210** is either mechanically and/or electromagnetically engaged with the piston **208** to drive the piston **208**. Importantly, the reciprocating pump **200** does not include any seals along the piston **208** or the pump cavity **206**. Unlike the pump shell **102** shown in FIGS. **1-3**, the pump shell first end **204**A of the reciprocating pump **200** shown in FIGS. **4-6** is closed to ambient atmosphere as shown in FIG. **4**. The pump cavity **204** further includes a drive chamber **212** located proximate to the pump shell first end **204**A, a working chamber **214** located proximate to the pump shell second end **204**B, and a reservoir **216** which is effectively a bulge in the pump cavity **206** between drive chamber **212** and the working chamber **214**. The reservoir **216** is preferably shaped as an annular ring. The drive chamber **212** and the working chamber **214** are preferably cylindrical in shape. Similarly, the piston **208** is preferably cylindrical in shape. The movement of the piston **208** causes working fluid to be drawn through a suction pipe **218** including a suction valve **220** into the working chamber **214** (with the delivery valve **224** closed) and then expel said working fluid out of the working chamber **214** through a delivery pipe **222** including a delivery valve **224** (with the suction valve **220** closed). The suction valve **220** and the delivery valve **224** are preferably mechanical check valves. Although check values are specified here, other types of valves may be used. In some embodiments, the reciprocating pump **200** pump shell **202** is formed of two parts including a first shell member **225** and a second shell member **226**. The second shell member **226** often is a "T" shaped member, to which the suction pipe **218** and the delivery pipe **222** are attached, preferably by welding. In such embodiments, the working chamber **214** is typically located inside the second shell member **226**. The first shell member **225** and the second shell member **226** are attached together, preferably by welding.

[0038] The drive system **210** preferably includes an electromagnetic driving unit such as the one described in U.S. Patent Application Publication Number 2017/0268491 entitled "Fluid Pump" to Ho, or the one described in U.S. Pat. No. 3,740,171 entitled "Electromagnetic Pump or Motor Device" to Farkos, the entire contents and teachings of which are incorporated herein by reference in their entireties. Although an electromagnetic drive system is shown in the figures, other drive systems are contemplated and could be used or adapted to work as a part of the reciprocating pump **200**. For example, mechanical drive systems such as that described in U.S. Pat. No. 5,403,169 entitled "Plunger Pump" to Yokoi et al., can be used. The entire contents and teachings of this reference is incorporated herein by reference. A mechanical crank with one or more connecting rods may also be used as the drive system **210**.

[0039] The reciprocating pump **200** preferably further includes a return pipe **227** in fluid communication with the reservoir **216** and the suction pipe **218**. A return pipe valve **228** located along the return pipe **227** is used for controlling flow of working fluid through the return pipe **227**. The reciprocating pump **200** further includes a feed pipe **230** in fluid communication with the reservoir **216** and the delivery pipe **222**. A feed pipe valve **232** located along the feed pipe **230** is used for controlling flow of working fluid through the feed pipe **230**.

[0040] The reciprocating pump **200** preferably further includes a reservoir sensor **234** for sensing a level of working fluid in the reservoir **216**. The reciprocating pump **200** preferably further includes a control system **236** in communication with the reservoir sensor **234**, the return pipe valve **228**, and the feed pipe valve **232**. The control system **236** may include a classic programmable logic controller (PLC), a computer or computers including one or more processors, a custom electronic printed circuit board (PCB), or other control device known to persons having ordinary skill in the art. The control system **136** may be in communication with an electromagnetic drive as shown in the figures. The control system **236** may be connected to these components using wires, through a wireless connection, or combinations thereof. The control system **236** is preferably operable to open the feed pipe valve **232** if the level of working fluid in the reservoir **216** goes below a preset threshold; and/or open the return pipe valve **228** if the level of working fluid in the reservoir **216** goes above a preset threshold. The control system **236** is also preferably operable to close the feed pipe valve **232** if the level of working fluid goes above a preset threshold. Similarly, the control system **236** is operable to close the return pipe valve **228** if the level of working fluid in the reservoir **216** goes below a preset threshold. In a preferred embodiment, the control system **236** can be configured to make sure that the feed pipe valve **232** and the return pipe valve **228** are not open at the same time. The level of working fluid is indicated by the reservoir sensor **234** with data fed to the control system **236**. Pressure created by action of the piston **208** helps to force working fluid through the feed pipe **230** into the reservoir **216** when the feed pipe valve **232** is open. The return pipe valve **228** and the feed pipe valve **232** are preferably solenoid valves, but other types of computer-controlled valves known to persons having ordinary skill in the art may be used.

[0041] An important feature of the reciprocating pump **200** shown in FIGS. **4-6** is the fact that the pump shell first end **204**A is closed such that the drive chamber **212** can be pressurized with a gas. By adding gas to the drive chamber **212** and controlled gas pressure in the drive chamber **212**, such pressurization can operate to prevent working fluid from leaking past the reservoir **216** into the drive chamber **212**. The gas(es) used preferably include one or more inert gases such as, for example, argon gas. The features for controlling gas pressure in the drive chamber **212** are described in more detail below.

[0042] The reciprocating pump **200** shown in FIGS. **4-6** preferably further includes a gas feed line **238** in fluid communication with the drive chamber **212**, a gas feed line valve **240** located along the gas feed line **238** for controlling flow of gas into the drive chamber **212**, a gas release line **242** in fluid communication with the drive chamber **212**, a gas release line valve **244** located along the gas release line **242** for controlling flow of gas out of the drive chamber **212**, and a pressure sensor **246** for sensing the pressure of gas inside the drive chamber **212**. The control system **236** is in communication with the gas feed line valve **240**, the gas release line valve **244**, and the pressure sensor **246**. The control system **236** may be connected to these components using wires, through a wireless connection, or combinations thereof. The control system **236** is preferably further operable to open the gas feed line valve **240** if gas pressure inside the drive chamber **212** is sensed by the pressure sensor **246** to reach or fall below a minimum threshold pressure; and/or open the gas release line valve **244** if gas pressure inside the drive chamber **212** is sensed by the pressure sensor **246** to reach or exceed a maximum threshold pressure. The control system **236** is preferably further operable to close the gas feed line valve **240** if gas pressure inside the drive chamber **212** is sensed by the pressure sensor **246** to go above a minimum threshold pressure; and/or close the gas release line valve **244** if gas pressure inside the drive chamber **212** is sensed by the pressure sensor **246** to fall below a maximum threshold pressure. In a preferred embodiment, the control system **236** can be configured to ensure that the gas feed line valve **240** and the gas release line valve **244** are not open at the same time.

[0043] The various components of the reciprocating pumps described above are preferably made of metal, metal alloy, and/or ceramic material for high temperature applications (e.g., pumping molten salt). The sizes and exact shapes of the components in the reciprocating pumps described above may vary. Alternatively, for lower temperature applications (i.e., less than 100° C.) such as hygienic applications, polymeric materials can be used (e.g., plastic).

[0044] In addition to the reciprocating pump **100** and the reciprocating pump **200** described above, a method of controlling the flow of working fluid being pumped through a reciprocating pump which uses no seals along a pump piston or pump cavity is disclosed as shown in FIG. **7**. Either the reciprocating pump **100** or the reciprocating pump **200** can be used for the initial operations including 300 collecting working fluid in a reservoir of the reciprocating pump; **302** opening the feed pipe valve if the level of working fluid in the reservoir goes below the preset threshold in order to raise the level of working fluid in the reservoir; and **304** opening the return pipe valve if the level of working fluid in the reservoir goes above the preset threshold in order to lower the level of working fluid in the reservoir. For the following operation, the reciprocating pump **200** would need to be used, the additional operations including 306 maintaining the gas pressure inside the drive chamber at a pressure ranging from the minimum threshold pressure to the maximum threshold pressure in order to prevent working fluid from entering the drive chamber.

[0045] An additional method of priming a reciprocating pump which uses no seals along a pump piston or pump cavity is also disclosed as shown in FIG. **8**. For this method either the reciprocating pump **100** or the reciprocating pump **200** may be used. The method includes 400 providing a reciprocating pump; **402** filling the reservoir with working fluid; and **404** activating the drive system to begin moving the piston so that the piston alternates between the first position to the second position and working fluid seeps into the working chamber to prime the reciprocating pump. Operation **402** if filling the reservoir with working fluid may be accomplished by filling material into the reservoir (**116** or **216**) through an access port (**148** or **248**) wherein the access port can be closed using a removable plug (**150** or **250**). For high temperature applications, salt can be added through the access port (**148** or **248**) which will later become molten when the temperature of the system reaches a certain level.

[0046] Embodiments in the disclosure are particularly well-suited for use at high temperatures (e.g., above 400° C.). One application for using embodiments described herein is pumping molten salt which must be kept at a high temperature. Other applications are contemplated which could require use at low or high temperatures. The previously described embodiments of the present disclosure have many advantages, including providing a way to pump high temperature fluids without the drawback of destroying pump seals due to the high temperature. Another advantage to the reciprocating pump **200** is that working fluid can be prevented from entering the drive chamber **212** by exerting high pressure gas in the drive chamber **212** to counter any tendency of working fluid to creep toward the drive chamber **212**. Also, by providing a reservoir and allowing working fluid to extend into space between the piston and the pump shell, the working fluid works as a partial seal. Additionally, working fluid the is initially placed in the reservoir can be used as a pump priming agent as working fluid leaves the reservoir and extends into space between the piston and the pump shell when the drive system is activated.

[0047] The foregoing description of preferred embodiments of the present disclosure has been presented for purposes of illustration and description. The described preferred embodiments are not intended to be exhaustive or to limit the scope of the disclosure to the precise form(s) disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of the principles of the disclosure and its practical application, and to thereby enable one of ordinary skill in the art to utilize the concepts revealed in the disclosure in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the disclosure as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

[0048] Any element in a claim that does not explicitly state "means for" performing a specified function, or "step for" performing a specific function, is not to be interpreted as a "means" or "step" clause as specified in 35 U.S.C. § 112, ¶6. In particular, the use of "step of" in the claims herein is not intended to invoke the provisions of 35 U.S.C. § 112, ¶6.

What is claimed is:

1. A reciprocating pump comprising:

a pump shell including a pump shell first end and a pump shell second end;

a pump cavity inside the pump shell, the pump cavity further comprising:

a working chamber proximate to the pump shell second end;

a drive chamber proximate to the pump shell first end; and

a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid;

a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity;

a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe;

a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity;

a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe;

a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe;

a drive system engaged with the piston for driving the piston inside the pump cavity;

a return pipe in fluid communication with the reservoir and the suction pipe;

a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe;
a feed pipe in fluid communication with the reservoir and the delivery pipe;
a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe;
a reservoir sensor for sensing a level of working fluid in the reservoir; and
a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to:
open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and
open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold.

2. The reciprocating pump of claim **1** wherein the reciprocating pump does not include any seals in the pump cavity or along the piston such that some working fluid is permitted to escape the working chamber and move into the reservoir during operation of the reciprocating pump.

3. The reciprocating pump of claim **1** wherein the pump shell includes a first end and a second end and wherein the first end is open to ambient atmosphere.

4. The reciprocating pump of claim **1** wherein the pump shell includes a first end and a second end and wherein the first end is closed to the atmosphere.

5. The reciprocating pump of claim **1** wherein the drive system comprises an electromagnetic driving unit and wherein the control system is operable to control the electromagnetic driving unit to cause the piston to move and alternate between the first position and the second position.

6. The reciprocating pump of claim **4** further comprising:
a gas feed line in fluid communication with the drive chamber;
a gas feed line valve located along the gas feed line for controlling flow of gas into the drive chamber;
a gas release line in fluid communication with the drive chamber;
a gas release line valve located along the gas release line for controlling flow of gas out of the drive chamber;
a pressure sensor for sensing the pressure of gas inside the drive chamber; and
the control system in communication with the gas feed line valve, the gas release line valve, and the pressure sensor wherein the control system is operable to:
open the gas feed line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to fall below a minimum threshold pressure; and
open the gas release line valve if gas pressure inside the drive chamber is sensed by the pressure sensor to reach a maximum threshold pressure.

7. The reciprocating pump of claim **6** wherein the operations of the control system are operable to control the pressure of gas in the drive chamber to limit an amount of working fluid that escapes from the working chamber to the reservoir and to prevent the working fluid from entering the drive chamber.

8. The reciprocating pump of claim **1** wherein the pump shell, the pump piston, the suction valve, and the delivery valve are made of material comprising metal or metal alloy.

9. The reciprocating pump of claim **1** wherein the pump shell, the pump piston, the suction valve, and the delivery valve are made of material comprising ceramic.

10. The reciprocating pump of claim **1** wherein the pump shell, the pump piston, the suction valve, and the delivery valve are made of material comprising plastic.

11. The reciprocating pump of claim **1** wherein the suction valve comprises a first check valve and the delivery valve comprises a second check valve.

12. The reciprocating pump of claim **1** wherein the return pipe valve comprises a first solenoid valve and wherein the feed pipe valve comprises a second solenoid valve.

13. A method of controlling a flow of working fluid being pumped through a reciprocating pump which uses no seals along a pump piston or pump cavity, the method comprising:
collecting working fluid in a reservoir of a reciprocating pump, the reciprocating pump comprising:
a pump shell including a pump shell first end and a pump shell second end;
a pump cavity inside the pump shell, the pump cavity further comprising:
a working chamber proximate to the pump shell second end;
a drive chamber proximate to the pump shell first end; and
a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid;
a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity;
a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe;
a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity;
a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe;
a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe;
a drive system engaged with the piston for driving the piston inside the pump cavity;
a return pipe in fluid communication with the reservoir and the suction pipe;
a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe;
a feed pipe in fluid communication with the reservoir and the delivery pipe;
a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe;
a reservoir sensor for sensing a level of working fluid in the reservoir; and
a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to:
open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and

open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold;

opening the feed pipe valve if the level of working fluid in the reservoir goes below the preset threshold in order to raise the level of working fluid in the reservoir; and

opening the return pipe valve if the level of working fluid in the reservoir goes above the preset threshold in order to lower the level of working fluid in the reservoir.

14. The method of claim **13** wherein the reciprocating pump further comprises:

a gas feed line in fluid communication with the drive chamber;

a gas feed line valve located along the gas feed line for controlling flow of gas into the drive chamber;

a gas release line in fluid communication with the drive chamber;

a gas release line valve located along the gas release line for controlling flow of gas out of the drive chamber;

a pressure sensor for sensing the pressure of gas inside the drive chamber; and

the control system in communication with the gas feed line valve, the gas release line valve, and the pressure sensor wherein the control system is operable to:

open the gas feed line valve if the gas pressure inside the drive chamber is sensed by the pressure sensor to fall to a minimum threshold pressure; and

open the gas release line valve if the gas pressure inside the drive chamber is sensed by the pressure sensor to reach to a maximum threshold pressure; and

wherein the method further comprises operations of:

maintaining the gas pressure inside the drive chamber at a pressure ranging from the minimum threshold pressure to the maximum threshold pressure in order to prevent working fluid from entering the drive chamber.

15. The method of claim **13** wherein the working fluid comprises a liquid.

16. The method of claim **13** wherein the working fluid consists of a liquid.

17. The method of claim **13** wherein the fluid comprises a multi-phase mixture of liquid, gas, and solids.

18. The method of claim **13** wherein the working fluid comprises molten salt.

19. The method of claim **13** wherein the working fluid consists of molten salt.

20. The method of claim **13** wherein the working fluid has a temperature of greater than 100° C.

21. The method of claim **13** wherein the working fluid has a temperature of greater than 400° C.

22. The method of claim **14** wherein the working fluid comprises a liquid.

23. The method of claim **14** wherein the working fluid consists of a liquid.

24. The method of claim **14** wherein the fluid comprises a multi-phase mixture of liquid, gas, and solids.

25. The method of claim **14** wherein the working fluid comprises molten salt.

26. The method of claim **14** wherein the working fluid consists of molten salt.

27. The method of claim **14** wherein the working fluid has a temperature of greater than 100° C.

28. The method of claim **14** wherein the working fluid has a temperature of greater than 400° C.

29. A method of priming a reciprocating pump which uses no seals along a pump piston or pump cavity, the method comprising:

providing a pump comprising:

a pump shell including a pump shell first end and a pump shell second end;

a pump cavity inside the pump shell, the pump cavity further comprising:

a working chamber proximate to the pump shell second end;

a drive chamber proximate to the pump shell first end; and

a reservoir comprising a bulge in the pump cavity between the working chamber and the drive chamber for storing and accumulating working fluid;

a suction pipe attached to the pump shell wherein the suction pipe is in fluid communication with the pump cavity;

a suction valve situated along the suction pipe for selectively restricting flow of working fluid through the suction pipe;

a delivery pipe attached to the pump shell wherein the delivery pipe is in fluid communication with the pump cavity;

a delivery valve situated along the delivery pipe for selectively restricting flow of working fluid through the delivery pipe;

a piston located inside the pump cavity and configured to alternate between a first position and a second position wherein such action is operable to draw working fluid through the suction pipe into the working chamber and then expel said working fluid out of the working chamber through the delivery pipe;

a drive system engaged with the piston for driving the piston inside the pump cavity;

a return pipe in fluid communication with the reservoir and the suction pipe;

a return pipe valve located along the return pipe for controlling flow of working fluid through the return pipe;

a feed pipe in fluid communication with the reservoir and the delivery pipe;

a feed pipe valve located along the feed pipe for controlling flow of working fluid through the feed pipe;

a reservoir sensor for sensing a level of working fluid in the reservoir; and

a control system in communication with the return pipe valve, the feed pipe valve, and the reservoir sensor wherein the control system is operable to:

open the feed pipe valve if the level of working fluid in the reservoir goes below a preset threshold; and

open the return pipe valve if the level of working fluid in the reservoir goes above a preset threshold;

filling the reservoir with working fluid; and

activating the drive system to begin moving the piston so that the piston alternates between the first position to the second position and working fluid seeps into the working chamber to prime the reciprocating pump.

* * * * *